Recent Progress in Developing A Global-Through-Urban Weather Research and Forecast Model with Chemistry (GU-WRF/Chem)

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Presentation Outline

- **Background and Motivation**
- **Development and Application of GU-WRF/Chem**
  - **Model Development Highlights**
  - **Current-Year Simulations**
    - **Model Application and Evaluation**
    - **Chemistry-Aerosol-Cloud-Radiation Feedbacks**
    - **Direct Effects on Shortwave Radiation and NO_2 Photolysis**
    - **Semi-Direct Effects on Planetary Boundary Layer (PBL) Meteorology**
    - **Indirect Effects on Cloud Condensation Nuclei (CCN), Cloud Droplet Number Concentration (CDNC) & Precipitation**
  - **Future-Year Simulations**
    - **Impact of Projected Emissions and Climate Change on Air Quality**
    - **GU-WRF/Chem vs. Community Climate System Model (CCSM)**
- **Major Findings and Future Work**

Development and Application of Global-through-Urban Weather Research and Forecasting Model with Chemistry (GU-WRF/Chem):

Hypotheses, Objectives, and Scientific Questions

- **Hypothesis**
  - **Climate change (CC) - air quality (AQ) feedbacks are important**
- **Objectives and Tasks**
  - **Develop a unified online-coupled model for integrated CC-AQ modeling**
  - **Conduct global-through-urban simulations for current/future scenarios**
  - **Replicate/quantify CC-AQ feedbacks and examine model uncertainties**
  - **Guide the win-win strategy for integrated CC mitigation and AQ control**
- **Scientific Questions**
  - **What are the important feedbacks of urban/regional air pollutants to CC?**
  - **How can CC and emission control affect urban/regional AQ?**
  - **What are key uncertainties associated with predicted effects/feedbacks?**

Development and Application of Global-through-Urban Weather Research and Forecasting Model with Chemistry (GU-WRF/Chem)

Model Development and Application Activities

- **Key Model Development**
  - **Globalize WRF/Chem**
  - **Compile global emissions (MOZART4, RETRO, IPCC, AeroCom); project future-year emissions based on IPCC A1B**
  - **Develop/improve model treatments for global-through-urban applications**
    - **Incorporate SAPRC99/CB05/CB05_GE, MADRID, FN05, & nucleation**
    - **Couple gaseous mechanisms with default and new aerosol/cloud modules**
    - **Add/improve other treatments (e.g., FTUV, dust, SOA, plume-in-grid)**

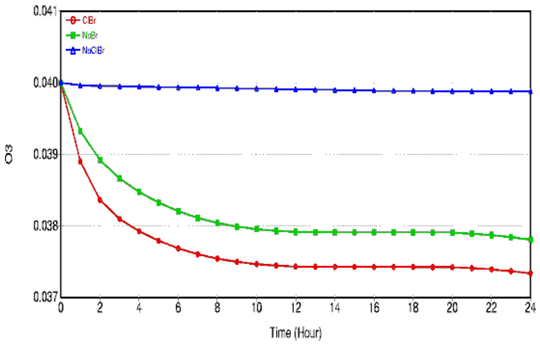
- **Model Evaluation of Current-Year (2001) Simulations**
  - **Met: T, QV, Precip, Radiation from NCEP/NCAR, NCDC, CMAP, TRMM, BSRN**
  - **Chem: O_3 and $PM_{2.5}$ from CASTNET, STN, IMPROVE, AIRS-AQS, SEARCH column CO, NO_2, and TOR from MOPITT, GOME, OMI, TOMS/SBUV**
  - **Other: AOD, CCN, CDNC, Cloud Fraction, COT, CER from MODIS**
- **Model Intercomparison and Trend Analysis of Future-Year Simulations**
  - **Intercomparison: 2050 GU-WRF/Chem vs. 2046-2055 10-yr average CCSM**
  - **Trend Analysis: 2010, 2020, 2030, 2040, and 2050 vs. 2001**

Development and Incorporation of CB05 for Global Extension (CB05_GE) into GU-WRF/Chem

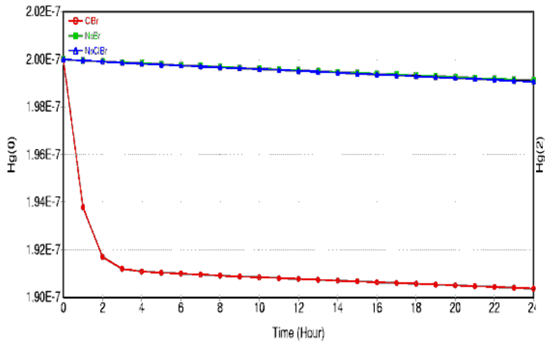
- **A Total of 120 New Reactions in CB05_GE**
  - 5 stratospheric reactions (O_2, N_2O, O^1D)
  - 78 reactions for 25 halogen species (48 for 14 Cl and 30 for 11 Br species)
  - 4 mercury reactions (Hg(0) and Hg(II))
  - 13 heterogeneous reactions on aerosol/cloud and 20 reactions on PSCs
  - H_2O, CH_4, CO_2, O_2 and H_2 are treated as chemically-reactive species
- **Box Model Test**
  - Four conditions: urban, upper troposphere, lower stratosphere, and Arctic
  - Several scenarios: NoClBr – no halogen chemistry (blue), ClBr – with full halogen chemistry (red), NoBr – with chlorine chemistry (green)

Arctic (March)

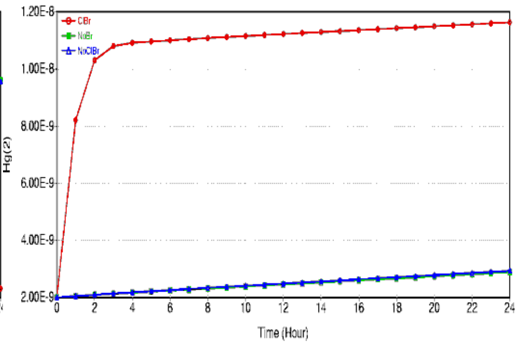
O_3



Hg(0)



Hg(II)

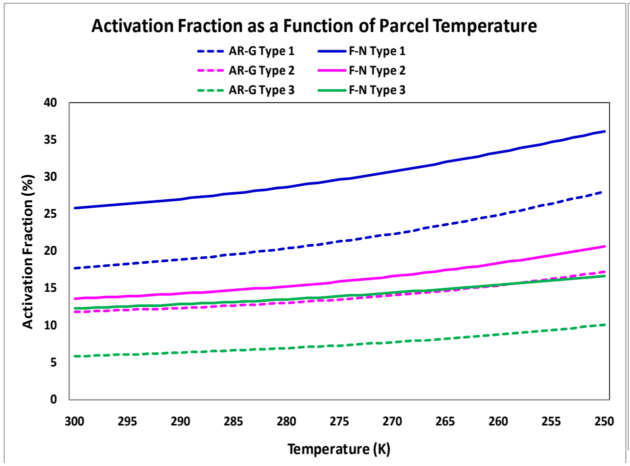


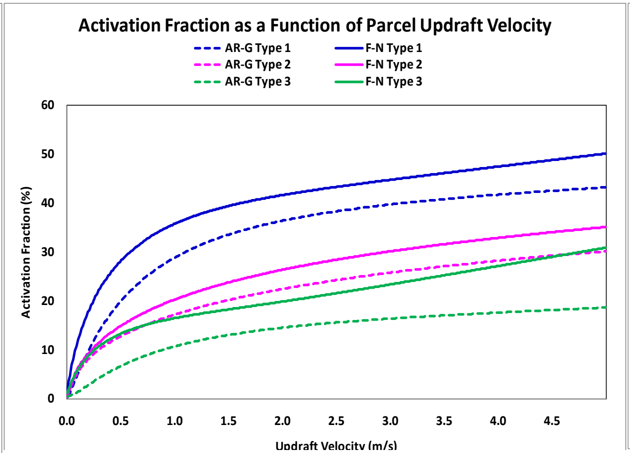
Simulated Aerosol Activation Fractions as a Function of Parcel Temperature and Updraft Velocity:

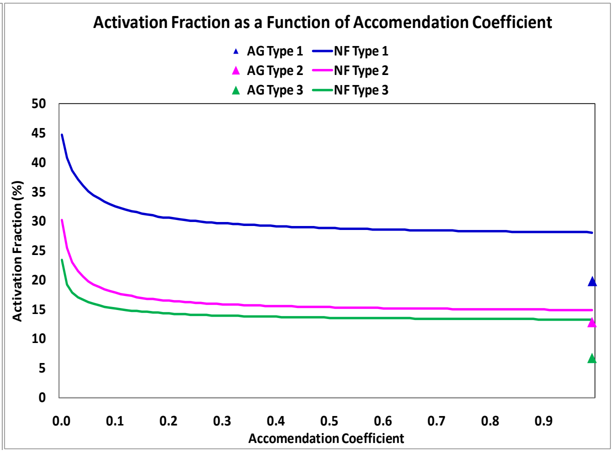
Uncertainty in Aerosol Activation Parameterizations

- **Two Activation Parameterizations**
  - ◆ **Abdul Razzak-Ghan 2000 (AR-G00) (Default in WRF/Chem)**
  - ◆ **Fountoukis-Nenes 2005 (F-N05)**
- **Box Model Test**
  - ◆ **Single aerosol type (sulfate), with a modal representation with 3 modes**
  - ◆ **Identical CCN spectrum in AR-G00 and F-N05**
  - ◆ **3 conditions: Marine (Type 1), Continental (Type 2), Remote Marine (Type 3)**

Parcel Temperature **Updraft Velocity** **Accommodation Coefficient**



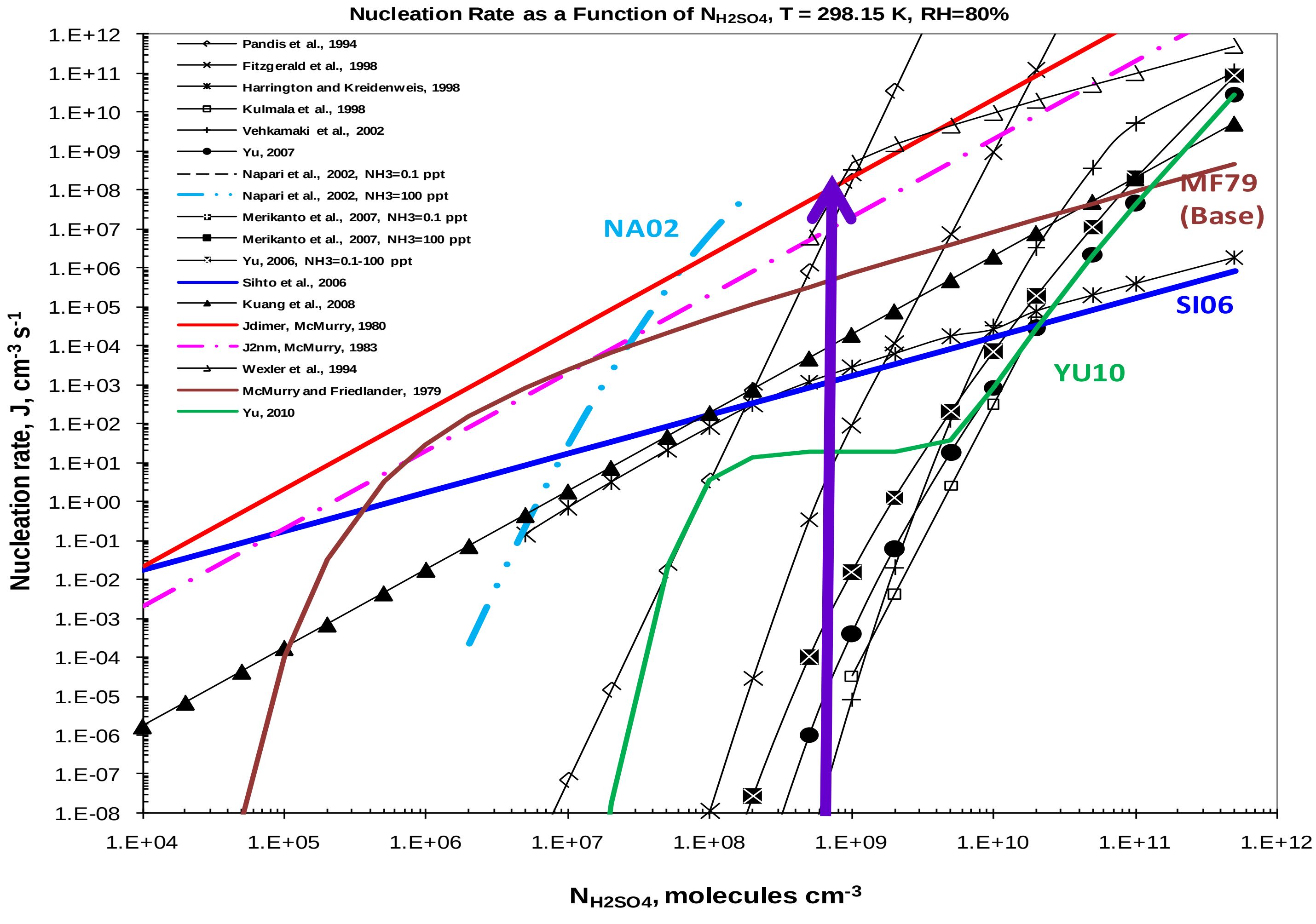




Aerosol activation fractions differ by up to a factor of 4

Simulated Nucleation Rates as a Function of N_{H2SO4}

Uncertainty in Nucleation Parameterizations



Nucleation rates differ by > 16 orders of magnitude

Nested GU-WRF/Chem Simulations

(Base Configurations: FTUV/CB05GE/MADRID/CMU/AR-G, 27 layers from 1000-50 mb)

- **Period:** **Met only:** 2001/2050, at 4° × 5° & 1° × 1°, w different physics options

  Gas and PM:

  1. 2001 Jan/Jul over D01-D04, w and w/o PM
  2. 2001, 2010, 2020, 2030, 2040, 2050 over D01

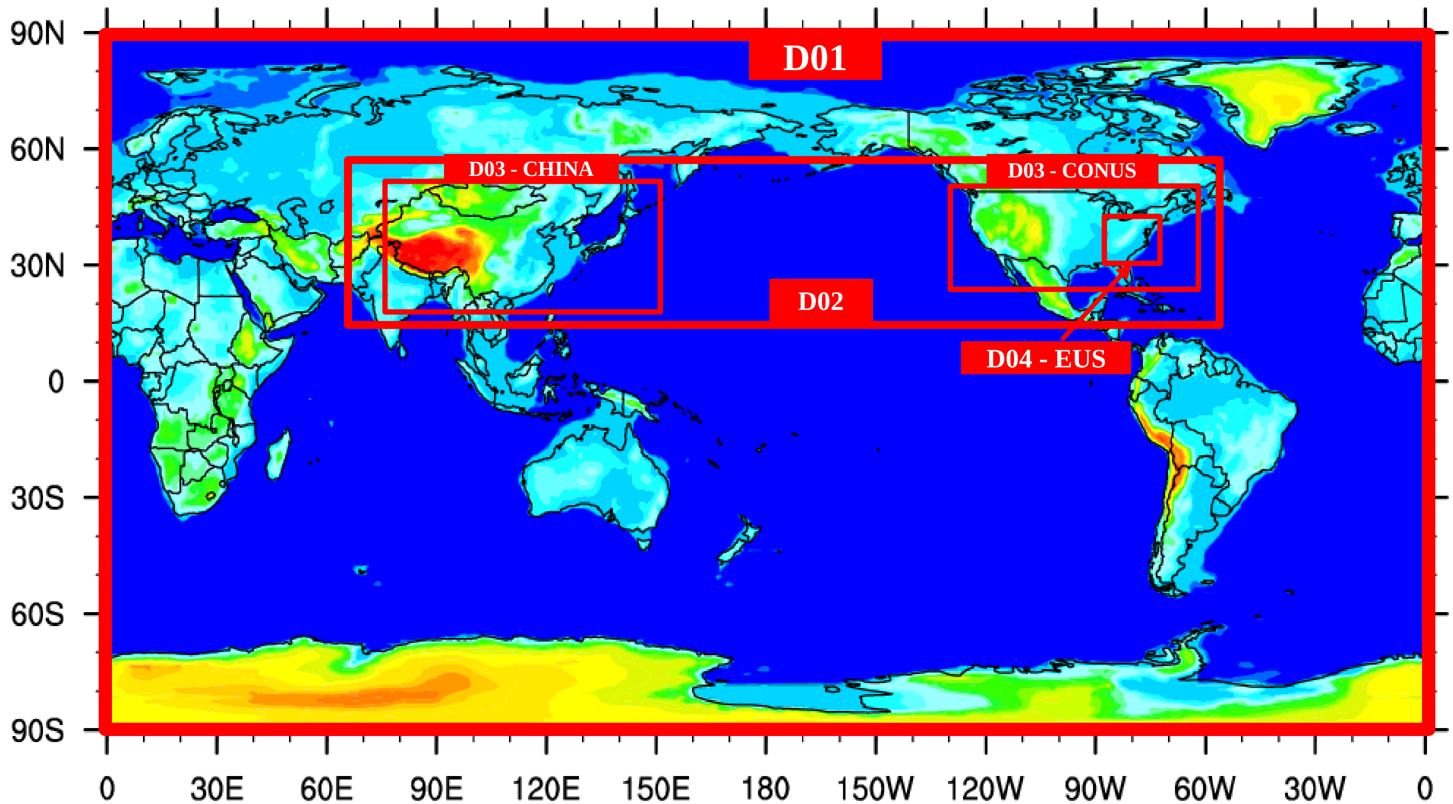
- **Domain:** **D01:** 4° × 5°, 45 (lat.) × 72 (long.) (Global)

  D02: 1.0° × 1.25°, 44 × 192 (Trans-Pacific)

  D03-CONUS: 0.33° × 0.42°, 84× 168 (CONUS)

  D03-China: 99× 177 (China)

  D04: 0.08° × 0.10°, 136× 144 (E. US)

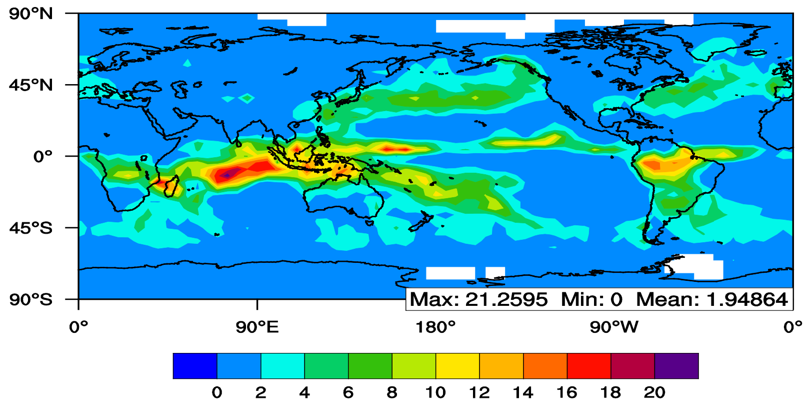


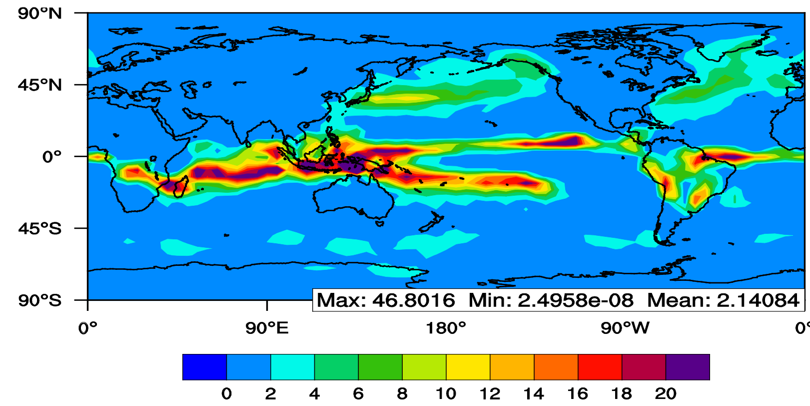
D01: Global D02: Trans-Pacific D03: CONUS and China D04: E. US

2001 Monthly Mean Daily Precipitation (mm/day)

Observation (CMAP) | **Simulation**

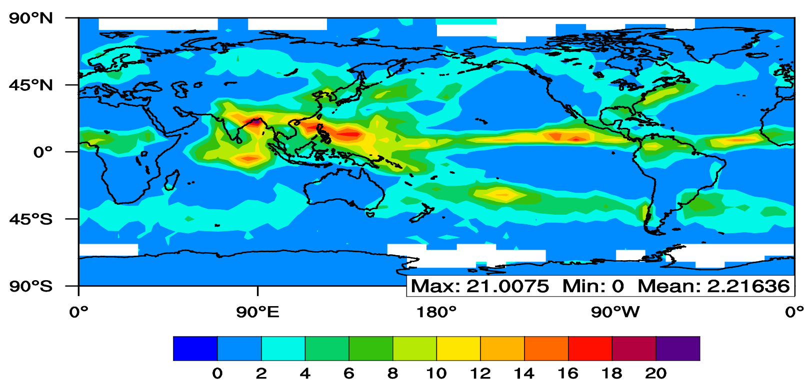
Jan.

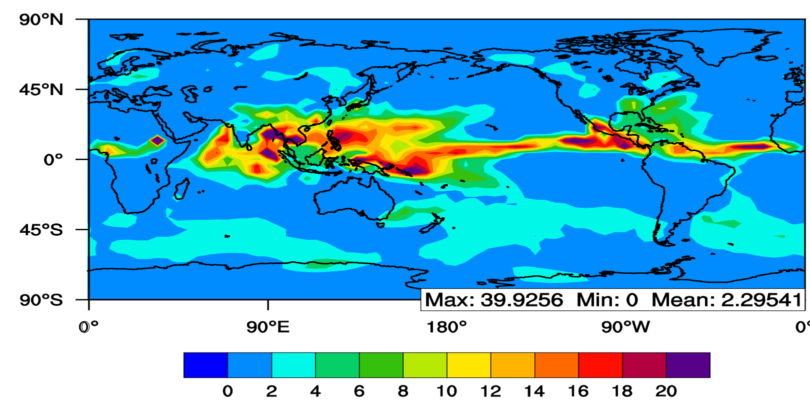




NMB = 11.5%

Jul.

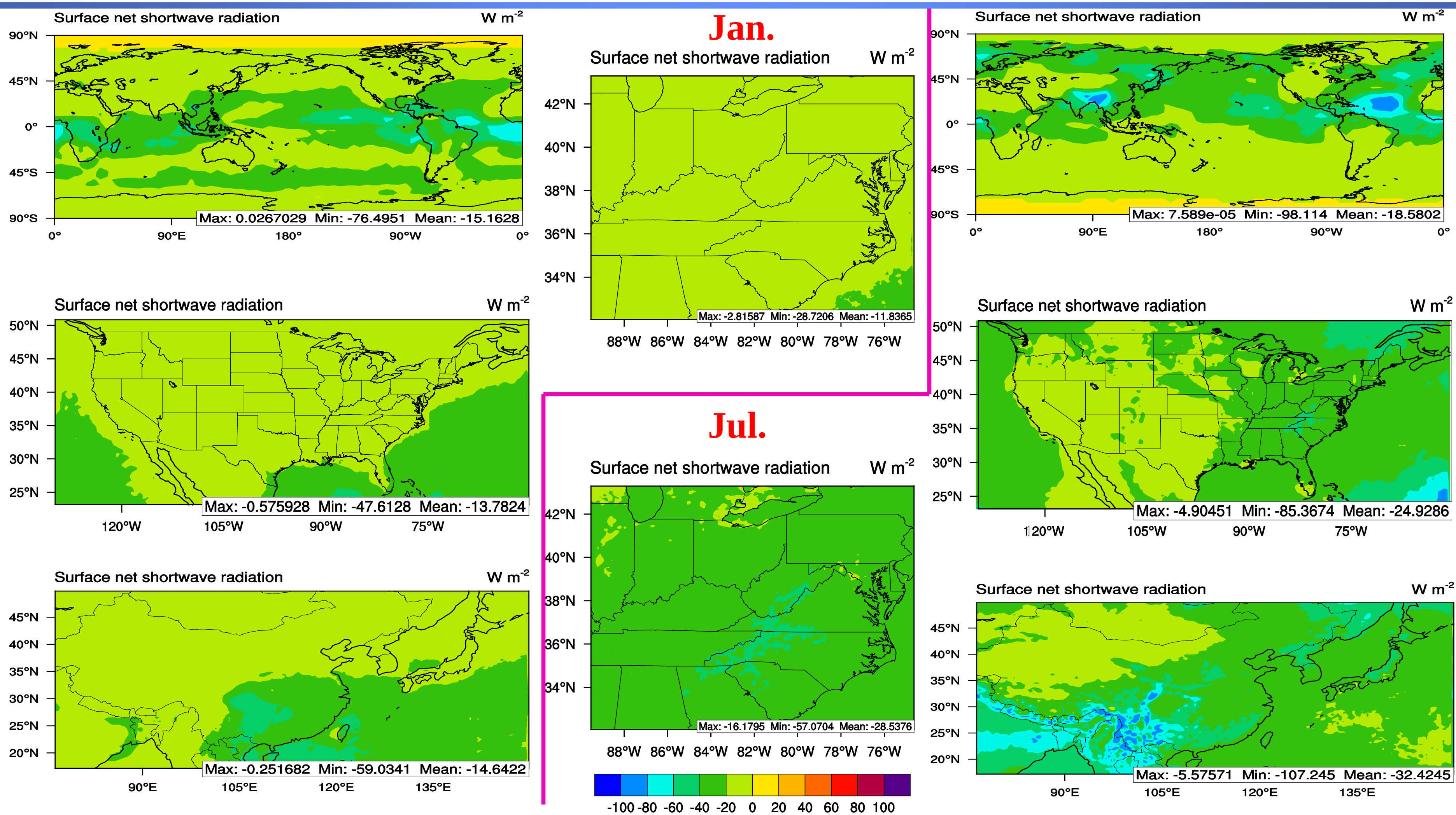




NMB = 5.7%

Direct Effects of $PM_{2.5}$ on Shortwave Radiation

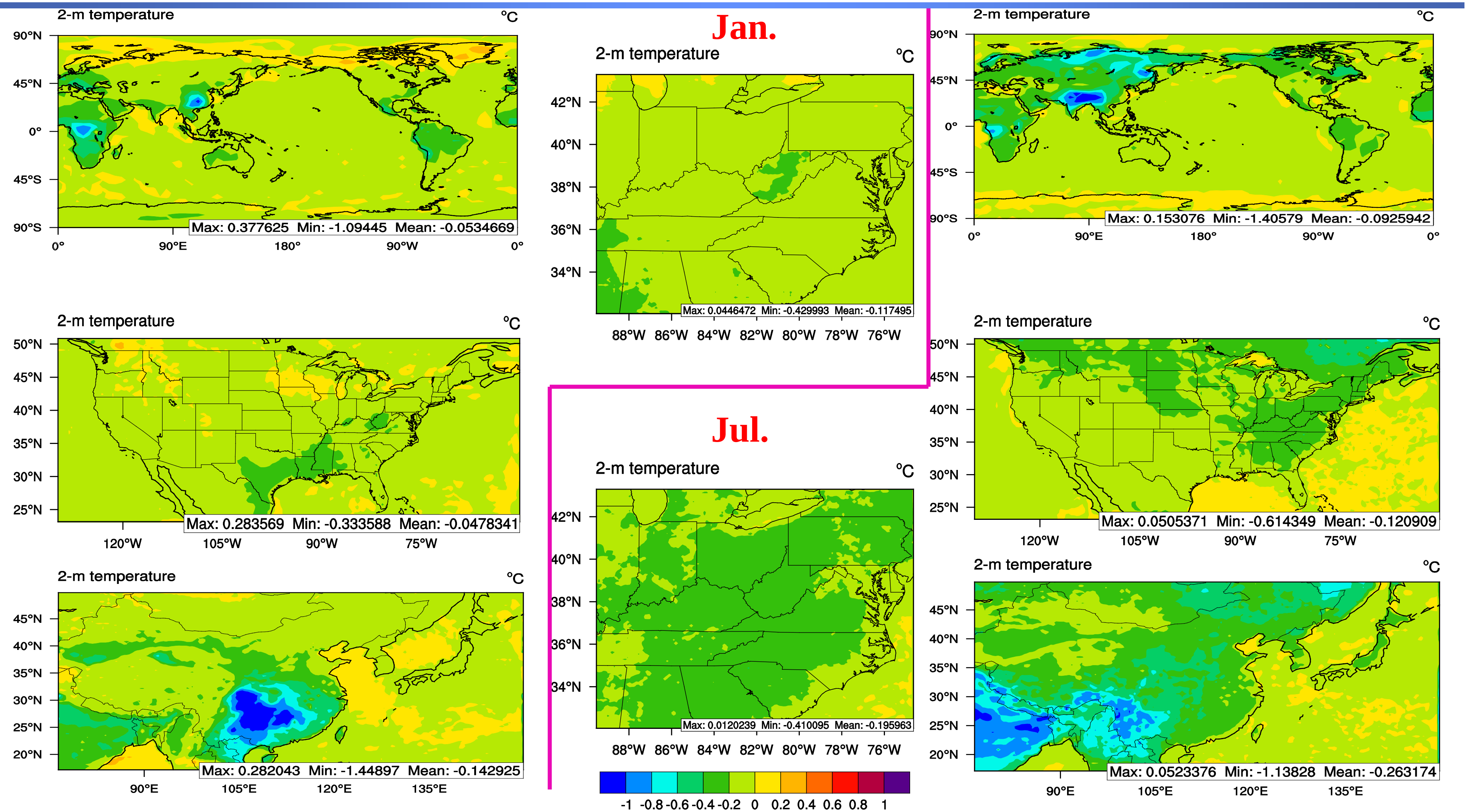
Jan. **Absolute Difference** **Jul.**



$PM_{2.5}$ decreases shortwave radiation domainwide by up to -45% (global mean: -10%)

Semi-Direct Effects of $PM_{2.5}$ on Temperature at 2-m

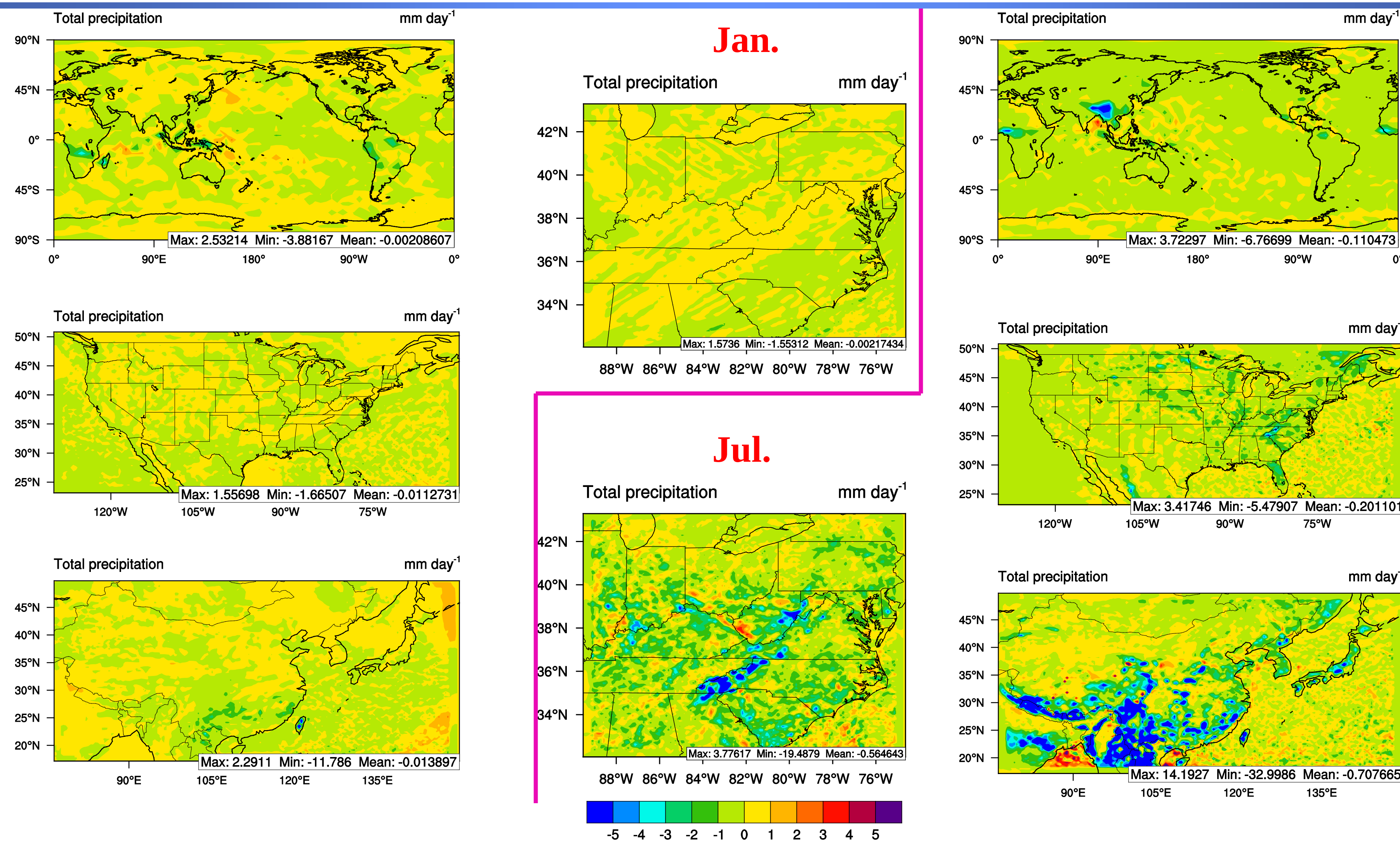
Jan. **Absolute Difference** **Jul.**



$PM_{2.5}$ decreases T2 over most areas up to -546% (global mean: -1.6%)

Indirect Effects of $PM_{2.5}$ on Precipitation

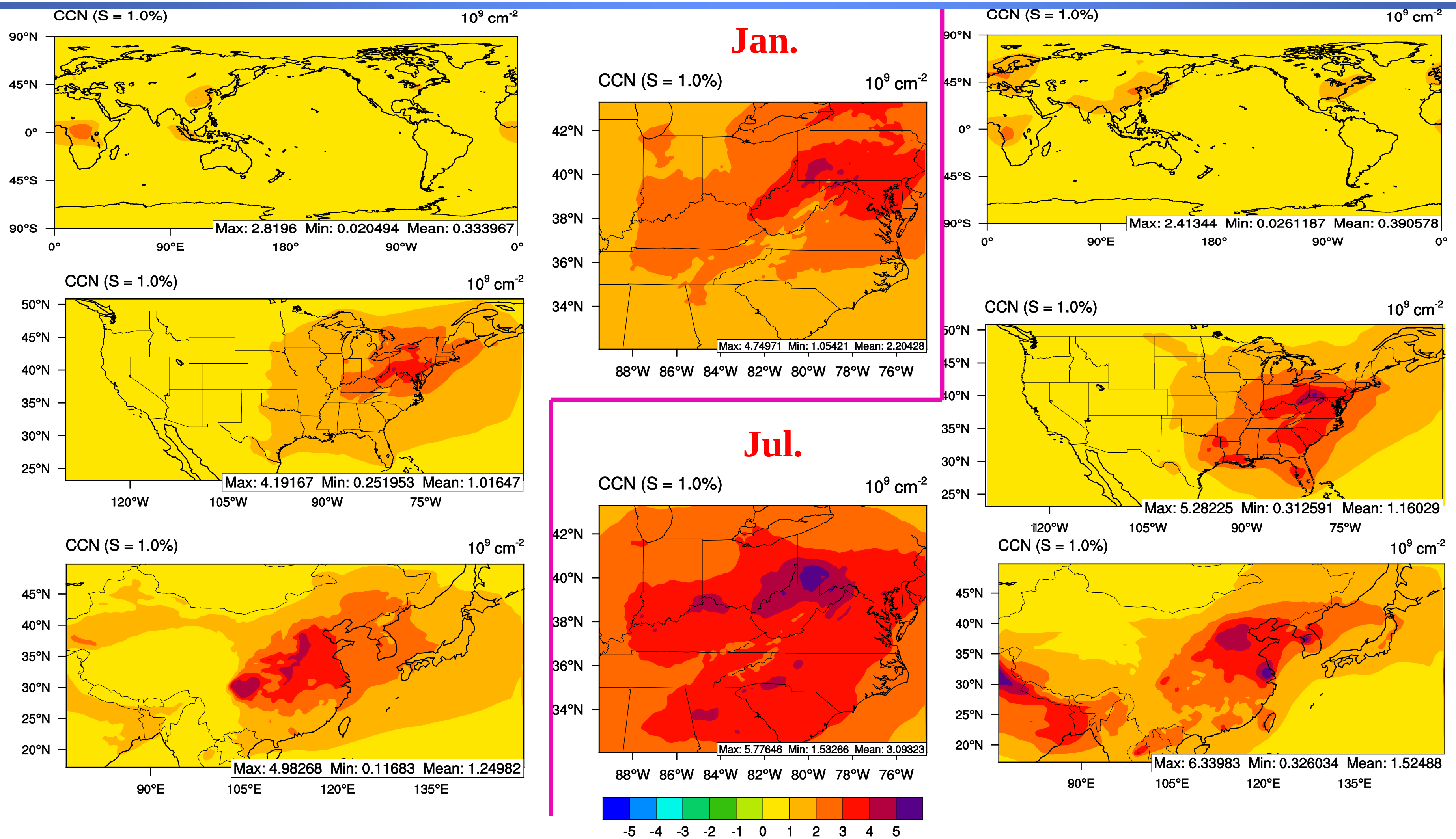
Jan. **Absolute Difference** **Jul.**



$PM_{2.5}$ decrease precipitation over polluted regions by up to -82% (global mean: -5%)

Indirect Effects of $PM_{2.5}$ on Column CCN (S=1%)

Jan. **Absolute Difference** **Jul.**



$PM_{2.5}$ enhances CCN domainwide by up to 3340% (global mean: 478%)

Major Findings and Future Work

- **GU-WRF/Chem demonstrates promising skills in reproducing observations**
- **Aerosol feedbacks to radiation, meteorology, and cloud microphysics**
  - **Aerosols decrease shortwave radiation by up to -45% (global mean: -10%)**
  - **Aerosols decrease NO_2 photolysis rate by up to -52% (global mean: -11%)**
  - **Aerosols decrease near-surface temperature by up to -546% (global mean: -1.6%)**
  - **Aerosols decrease PBL height by up to -39% (global mean: -1.7%)**
  - **Aerosols increase to CCN by up to 3340% (global mean: 478%)**
  - **Aerosols increase to CDNC by up to 5751% (global mean: 318%)**
  - **Aerosols decrease precipitation by up to -82% (global mean: -5%)**
- **Simulated aerosol, radiation, and cloud properties exhibit small-to-high sensitivity to nucleation and aerosol activation parameterizations**
  - **Higher sensitivity to nucleation parameterizations: PM mass and number, CCN, Precip**
  - **Higher sensitivity to activation parameterizations: AOD, COT, CDNC, LWP, R_{eff}**
  - **Small sensitivity: OLR, GLW, GSW, SWDOWN, RSWTOA, CF**
- **Observations are needed to verify feedbacks, improve models, and reduce the uncertainties in simulated aerosol direct and indirect effects**
- **Use feedbacks to guide win-win emission control strategies for CC/AQ**
  - **Isolate and quantify complex speciated feedbacks: GHGs, cooling and warming PM**
  - **Assess the effectiveness of O_3 and PM attainment plans under different future emission scenarios and a changing climate**

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